



Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-352

Proposal Title: Nitrogen Fixation Using Nano-Photocatalytic Non-Thermal Plasma

Project Manager Information

Name: Roger Ruan

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

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Project Basic Information

Project Summary: Develop a novel technology to produce nitrogen fertilizers from water and air using nano-photocatalysts and non-thermal Plasma for direct and onsite application.

Funds Requested: \$555,000

Proposed Project Completion: 2024-06-30

LCCMR Funding Category: Water Resources (B)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Nitrogen fertilizer is in great demand in agriculture. Minnesota imports up to \$800 million retail value of nitrogen fertilizer annually. Traditionally, ammonia, one of the predominant components in nitrogen fertilizer, has been produced with the Haber- Bosch process using hydrogen and nitrogen for over 100 years. However, this process is energy-intensive and requires extremely high pressures (~100 atm) and high temperatures (~700 K) using large amounts of fossil orgrin H2. A large concomitant emission of CO2, a green-house gas, is generated along in the process. Therefore, a clean and renewable approach is highly sought after.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

Catalytic non-thermal plasma (cNTP) provides an alternative way to facilitate green synthesis of nitrogen fertilizers in an energy efficient way. Nitrogen is fixed from water and air using photocatalysts/modified photocatalysts such as TiO2 and doped TiO2 in the NTP discharge (Figure 1). The objectives of the project are to (1) develop and construct experimental catalytic NTP apparatuses in collaboration with industry partners, (2) improve the production of fertilizer nitrogen compounds via optimizing the key processing variables and conditions, i.e. photocatalysts, feed gas, voltage, NTP reactor design, UV intensity, wavelength, etc., (3) investigate the energy consumption and environmental impacts of the technology, and (4) develop recommendations for technology transfer and further R & D efforts.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

The specific project outcome will include the development of energy efficient photocatalysts, optimal processing conditions for high yield of nitrogen fertilizers, and a pilot-scale nitrogen fixation system for systems analysis and demonstration. These outcomes will move the technology closer to commercial implementation, which will help produce renewable nitrogen fertilizers, reduce fossil energy demand, and reduce CO2 emission, and thus reduce environmental impacts of nitrogen production industry and agricultural activities, and conserve natural resources.

Activities and Milestones

Activity 1: Scale up an integrated catalytic nitrogen fixation system and test the system in fields

Activity Budget: \$200,000

Activity Description:

We will communicate our findings from Activity 1 to primary stakeholders such as fertilizer producers, farmers, and farm machine manufacturers. Based their feedbacks, we will design and construct a small pilot scale integrated system for comprehensive evaluation of the technology. Rigorous tests will be conducted in lab and then we will move the system to field for testing and demonstration.

Activity Milestones:

Description	Completion Date
The process will be scaled up and a small pilot production system will be fabricated	2023-03-31
The pilot system will be tested and mass and energy balance data will be generated	2023-06-30
Field demonstration of the system will be conducted	2023-12-31

Activity 2: Evaluate environmental impacts and economic performance

Activity Budget: \$155,000

Activity Description:

The mass and energy balance data together with emission data will be used to evaluate the environmental and economic performance using mathematics models. This evaluation will provide good assessment of the environmental impact of the proposed technology. Further R&D efforts and commercialization strategy will be recommended.

Activity Milestones:

Description	Completion Date
The energy efficiency, cost, and emission will be evaluated	2023-12-31
Environmental impacts will be assessed	2024-06-30
Further R&D and commercialization strategy will be recommended	2024-06-30

Activity 3: Develop an experimental catalytic NTP apparatus and optimize the synthesis process

Activity Budget: \$200,000

Activity Description:

The concept of synthesizing nitrogen compounds using NPT has been proven in our preliminary studies. New and cost effective catalysts need to be developed and studied and processing parameters such as background gas, NTP reactor type need to be understood and optimized. In this activity, we will first develop a bench scale synthesis system that can house different types of NTP reactors and allow inclusion of catalysts. Common catalysts for synthesis of ammonia (NH₃), ammonium (NH₄⁺), nitrate (NO₃⁻), and nitrite (NO₂⁻), and UV reactive and visible light reactive photocatalysts will be prepared and investigated. Experiments will be conducted under different conditions to understand and optimize the process in terms of product yield, quality (composition), and energy efficiency.

Activity Milestones:

Description	Completion Date
A bench scale synthesis system will be developed and be operational	2022-03-31
Photocatalysts will be prepared and characterized	2022-03-31
New knowledge of the process works will be obtained	2022-06-30
The process will be optimized	2022-12-31

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Yanling Cheng	University of Minnesota	co-PI	No
Paul Chen	University of Minnesota	co-PI	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this be funded?

New scientific knowledge on plasma-based catalytic nitrogen fixation process will be acquired through research, and the demonstration will help raise significant interests from the public. We will seek industry partners and private, state, and federal funding to further develop and eventually commercialize the technology.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Demonstrating Innovative Technologies to Fully Utilize Wastewater Resources	M.L. 2014, Chp. 226, Sec. 2, Subd. 08c	\$1,000,000
Development of Innovative Sensor Technologies for Water Monitoring	M.L. 2016, Chp. 186, Sec. 2, Subd. 04j	\$509,000

Project Manager and Organization Qualifications

Project Manager Name: Roger Ruan

Job Title: Professor and Director

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Roger Ruan, Professor and Director, Center for Biorefining and Department of Bioproducts and Biosystems Engineering, University of Minnesota, Fellow of ASABE and Fellow of IFT, is the project manager of the proposed project. Dr. Ruan's research focuses on renewable energy technologies, solid and liquid waste treatment and utilization, and environmental engineering. Specifically, he has conducted research and published his findings in the areas of municipal, agricultural, and industrial wastewater treatment and utilization through novel anaerobic digestion, microalgae cultivation, and hydroponic cultivation, biomass and solid wastes (including plastics) gasification and pyrolysis, airborne pathogen disinfection, catalysis, non-thermal plasma, ammonia synthesis, etc. He is a top-cited author in the area of agricultural and biological sciences with an h-index of 63, i10-index of 255, and over 15,400 citations, and has received over 180 projects totaling over \$45 million in various funding for research, including major funding from USDA, DOE, DOT, DOD, LCCMR, and industries. He was the project manager of several earlier LCCMR funded projects which resulted in the issuance of a US patent and licensing of a technology. Therefore he has the technical expertise and project management experience to ensure the execution of proposed projects.

Organization: U of MN - College of Food, Agriculture and Natural Resource Sciences

Organization Description:

The Center for Biorefining is a University of Minnesota research center and help coordinate the University efforts and resources to conduct exploratory fundamental and applied research; provide education on bioenergy, biochemicals and

biomaterials; stimulate collaboration among the University researchers, other public sector investigators, and private investigators involved in biobased production technology development; promote technology transfer to industries; and foster economic development in rural areas. The Center's research programs are funded by DOE, USDA, DOT, DOD, LCCMR, IREE, Xcel Energy, and other federal and state agencies, NGOs, and private companies. The Center is equipped with state of the arts analytical instruments, and processing facilities ranging from bench to pilot scale.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	\$ Amount
Personnel								
Roger Ruan		Principal Investigator			36.5%	0.12		\$24,328
Paul Chen		Co-Principal Investigator			36.5%	0.48		\$64,621
Post Doc		Researcher			25.4%	3		\$193,799
Graduate Resesarch Assistant		Resesarch Assistant			45%	1.5		\$150,933
							Sub Total	\$433,681
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Materials and lab supplies including chemicals for analysis, catalysts, consumable supplies for analytical instruments, external analysis, glassware, etc.	For running experiments and operating the systems.					\$13,319
	Equipment	Components for fabrication of experimental apparatus, including NTP reactors, power supply, catalyst bed, UV light, mixer, pipes, pumps, control, etc.	To fabricate experimental apparatus and small system for running experiments, conducting performance analysis, and demonstration					\$100,000
							Sub Total	\$113,319
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-

Travel In Minnesota								
	Miles/ Meals/ Lodging	Travel	Travel					\$2,000
							Sub Total	\$2,000
Travel Outside Minnesota								
							Sub Total	-
Printing and Publication								
							Sub Total	-
Other Expenses								
		Repairs and Maintenance	Repairs and Maintenance of analytical instruments					\$6,000
							Sub Total	\$6,000
							Grand Total	\$555,000

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
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Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	-
Non-State				
			Non State Sub Total	-
			Funds Total	-

Attachments

Required Attachments

Visual Component

File: [99b55fdd-480.pdf](#)

Alternate Text for Visual Component

Showing the proposed process to convert water and air to nitrogen fertilizers which can be directly applied to field.

Optional Attachments

Support Letter or Other

Title	File
UMN authorization letter	f32e9f30-c44.pdf
UMN financial audit report	e0e43b46-90d.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

- Patent, Copyright, or Royalty Potential

Does your project include research?

Yes

Does the organization have a fiscal agent for this project?

No

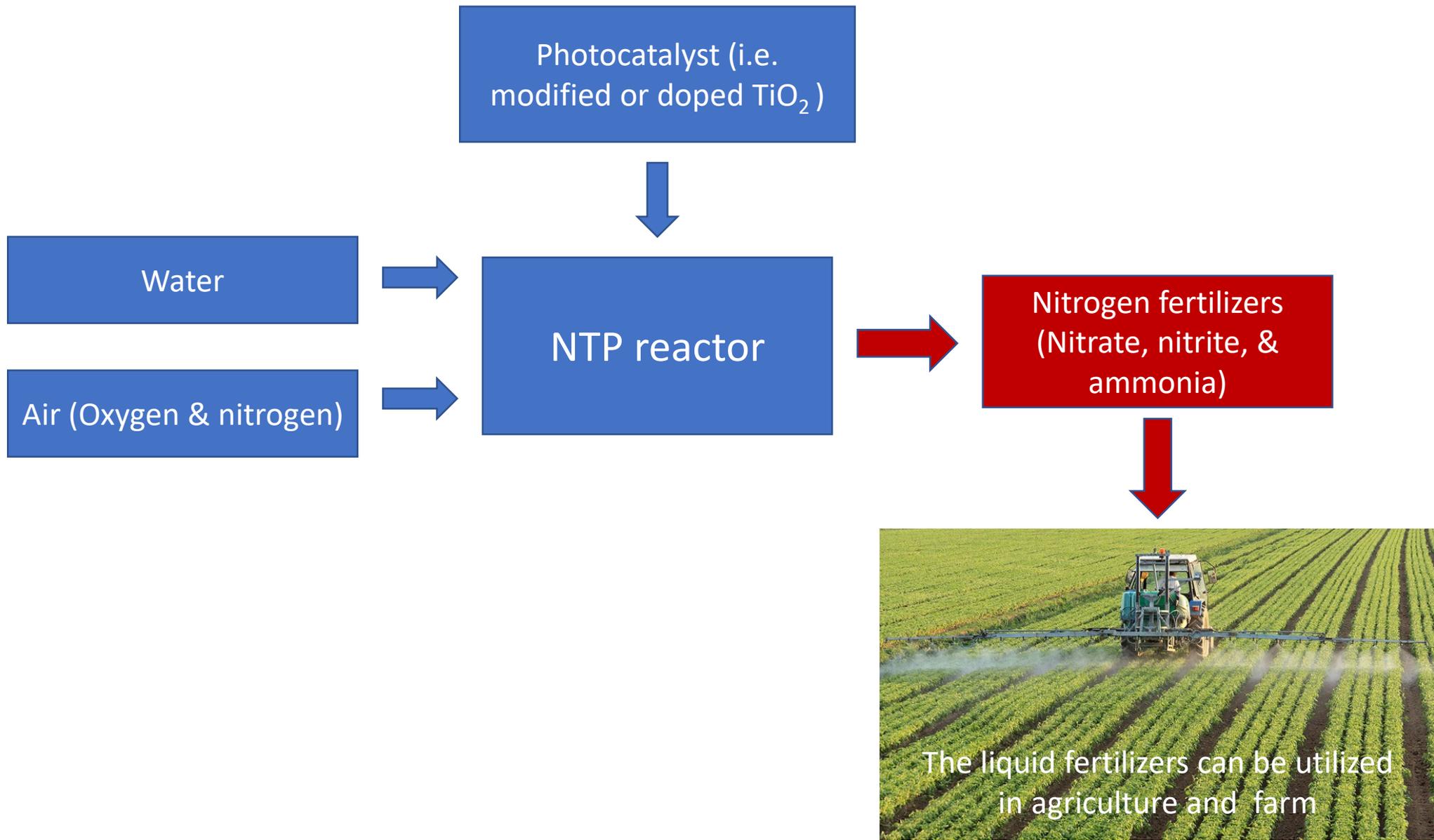


Figure 1. Nitrogen fertilizer generation and application